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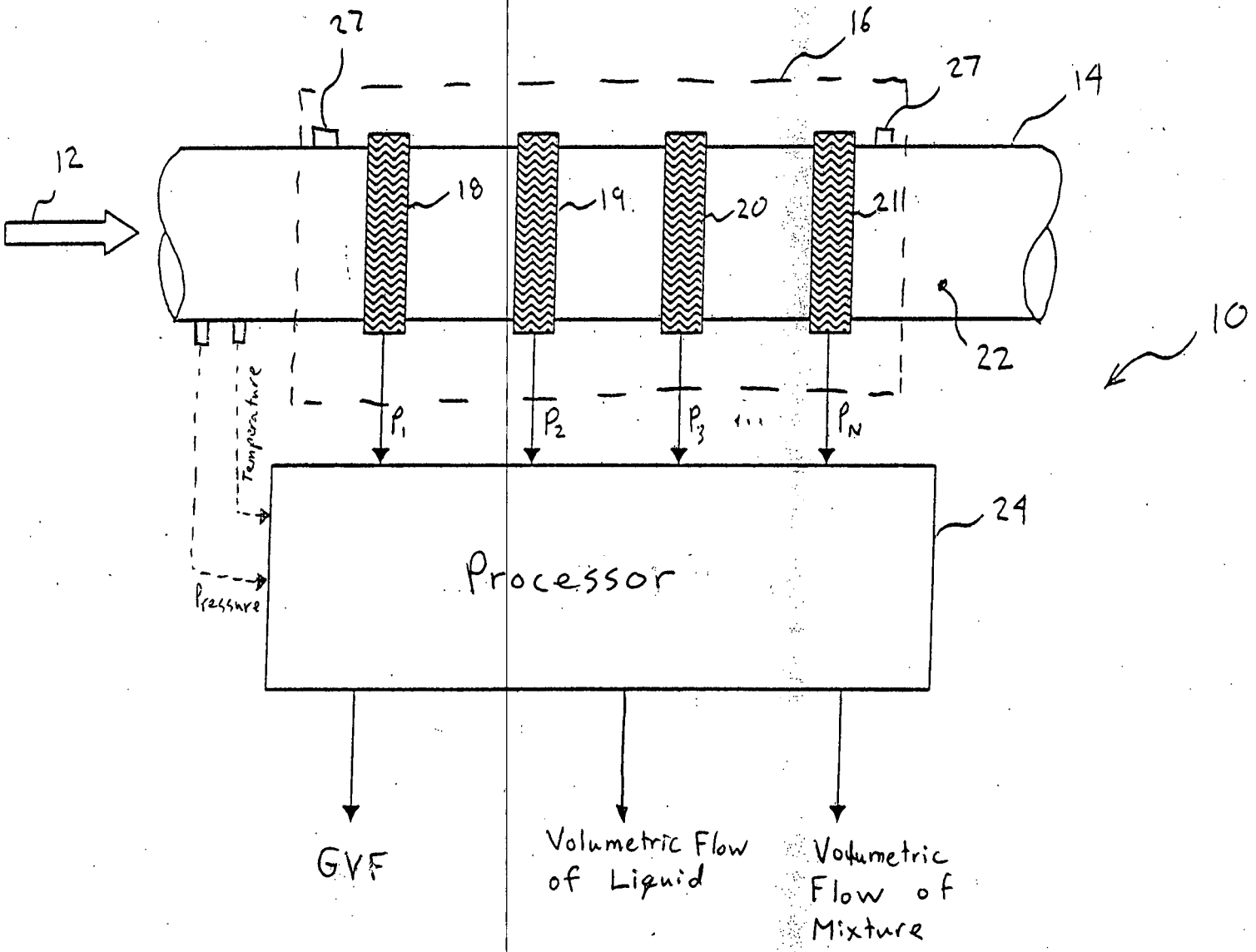

27
16
27
14
12
18
19
20
21
22
10
Temperature
Pressure
P_1
P_2
P_3
...
P_N
24
Processor
GVF
Volumetric Flow of Liquid
Volumetric Flow of Mixture

Fig. 1

CC-0714

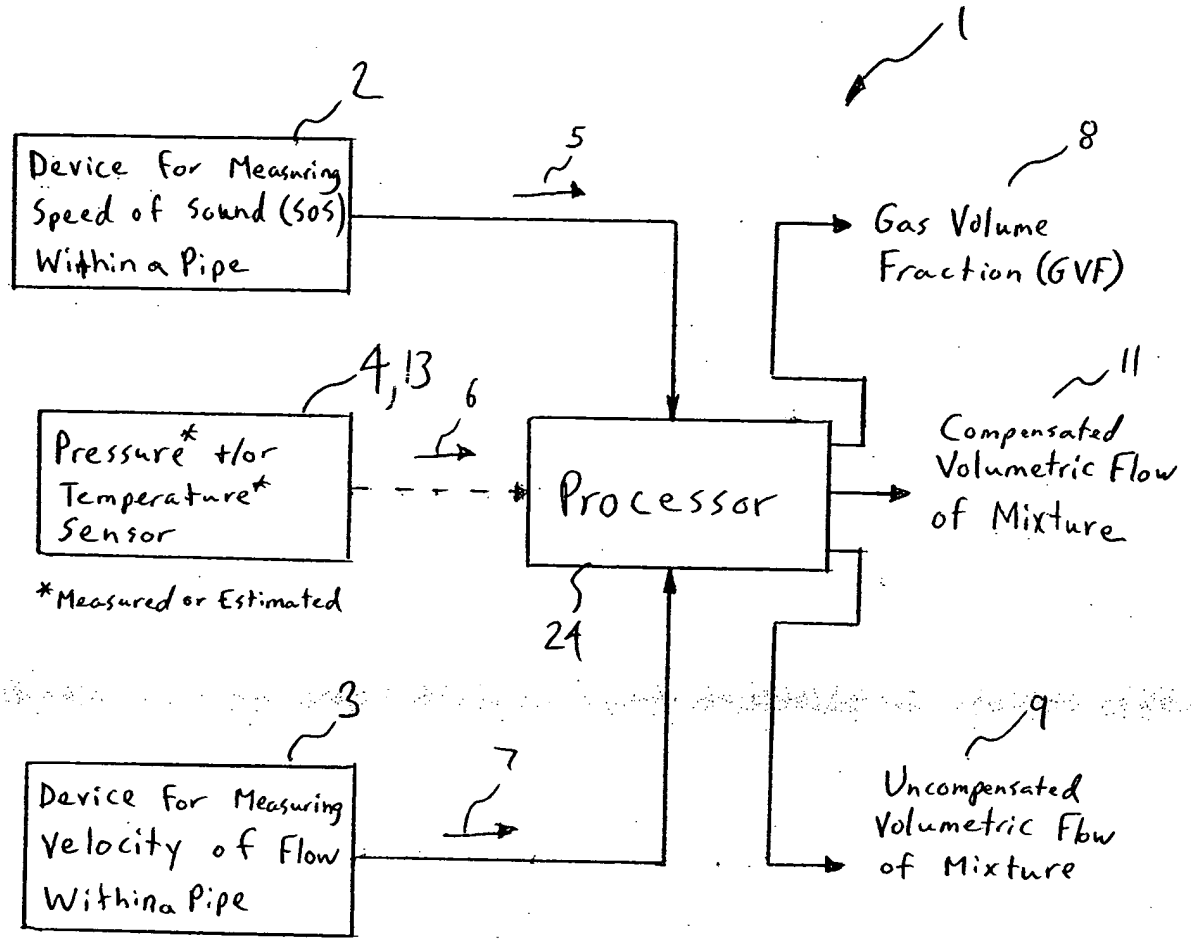

1
2
Device for Measuring Speed of Sound (SOS) Within a Pipe
5
8
Gas Volume Fraction (GVF)
4,13
6
11
Pressure* t/or Temperature* Sensor
Processor
Compensated Volumetric Flow of Mixture
*Measured or Estimated
24
3
9
7
Device For Measuring Velocity of Flow Within a Pipe
Uncompensated Volumetric Flow of Mixture

Fig. 2

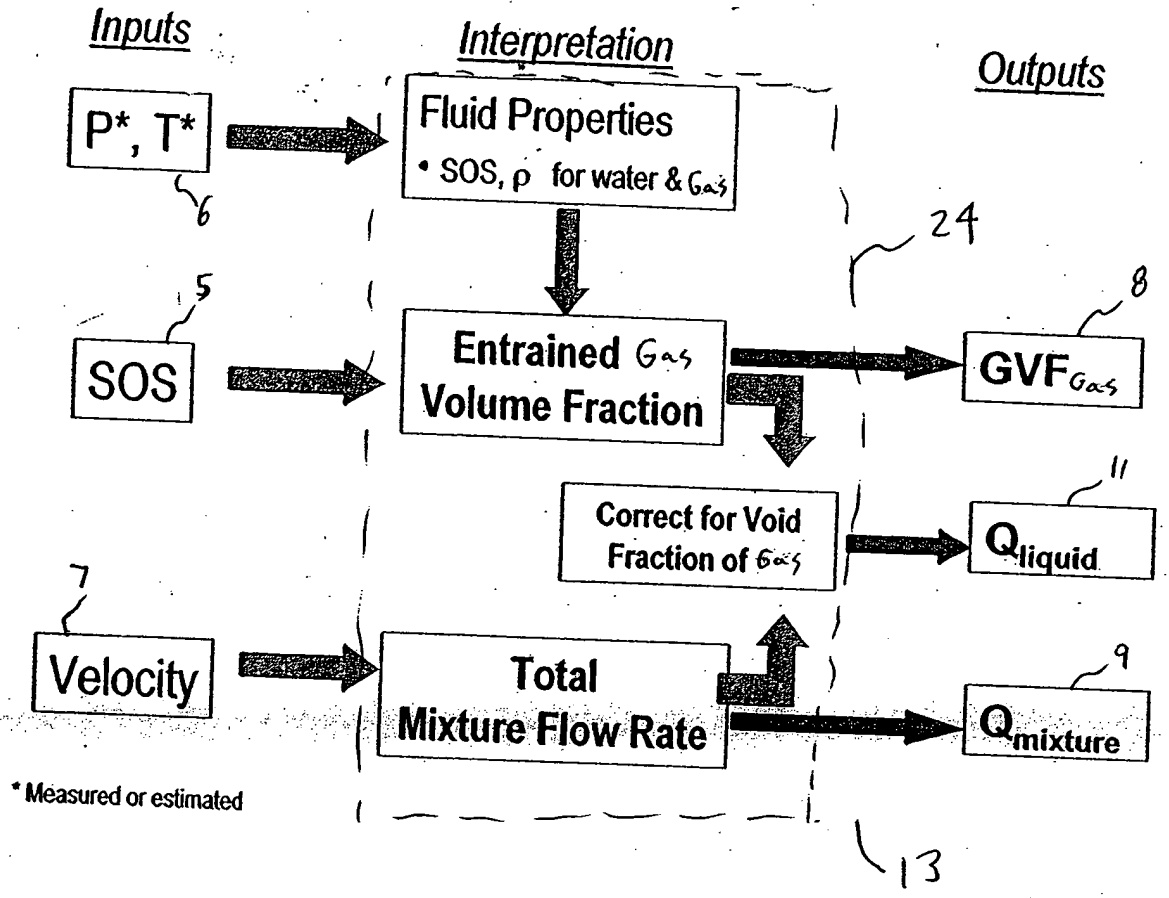

Inputs
Interpretation
Outputs
P*, T*
6
Fluid Properties
• SOS, ρ for water & Gas
24
5
SOS
Entrained Gas Volume Fraction
8
GVF Gas
Correct for Void Fraction of Gas
11
Q liquid
7
Velocity
Total Mixture Flow Rate
9
Q mixture
* Measured or estimated
13

Fig. 3

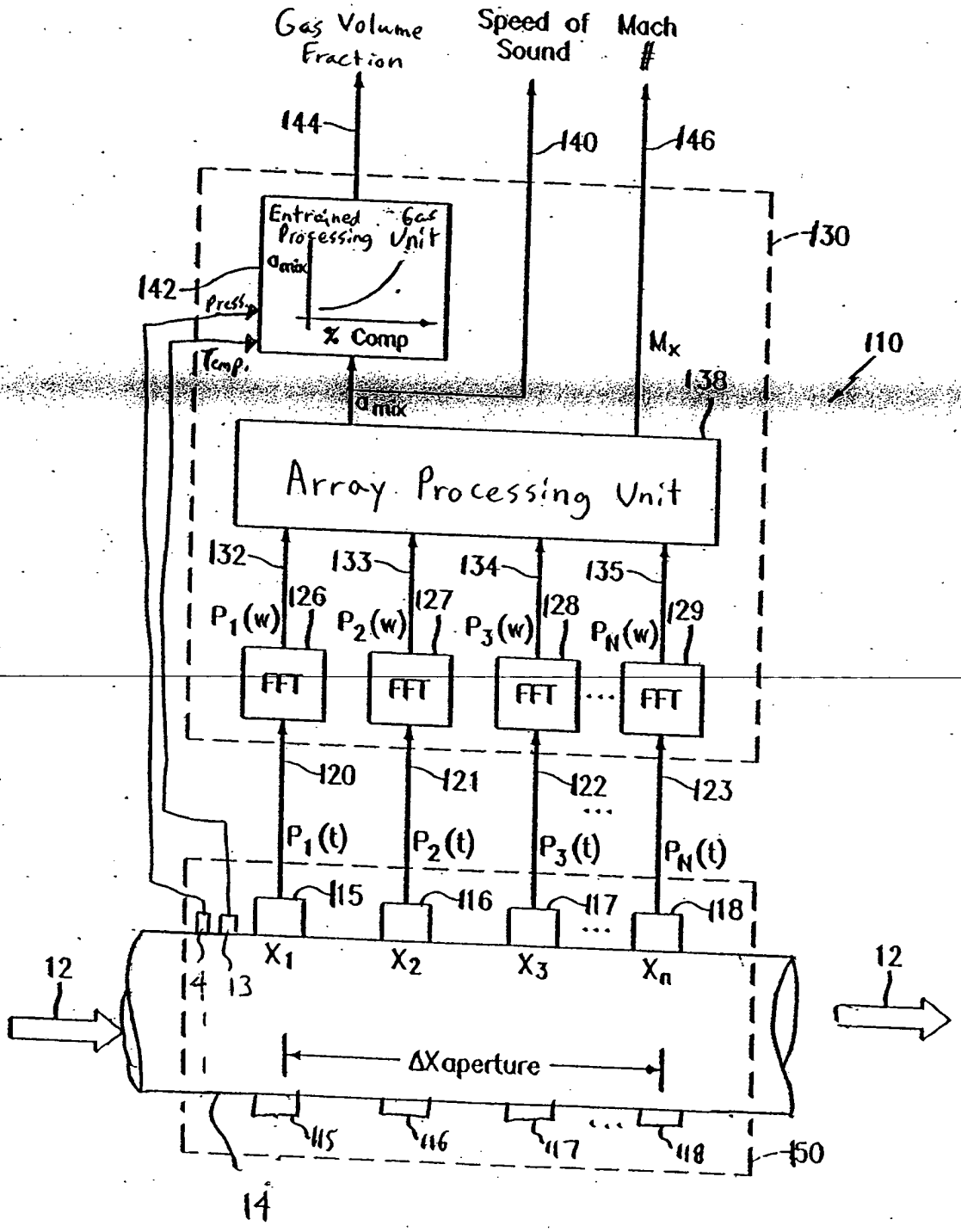

Gas Volume Fraction
Speed of Sound
Mach #
144
140
146
Entrained Gas Processing Unit
a_{mix}
Press.
Temp.
% Comp
142
130
110
M_x
138
a_{mix}
Array Processing Unit
132
133
134
135
126
127
128
129
$P_1(w)$
$P_2(w)$
$P_3(w)$
$P_N(w)$
FFT
FFT
FFT
FFT
120
121
122
123
$P_1(t)$
$P_2(t)$
$P_3(t)$
$P_N(t)$
115
116
117
118
X_1
X_2
X_3
X_n
12
12
4
13
$\Delta X_{aperture}$
115
116
117
118
150
14

FIG. 4

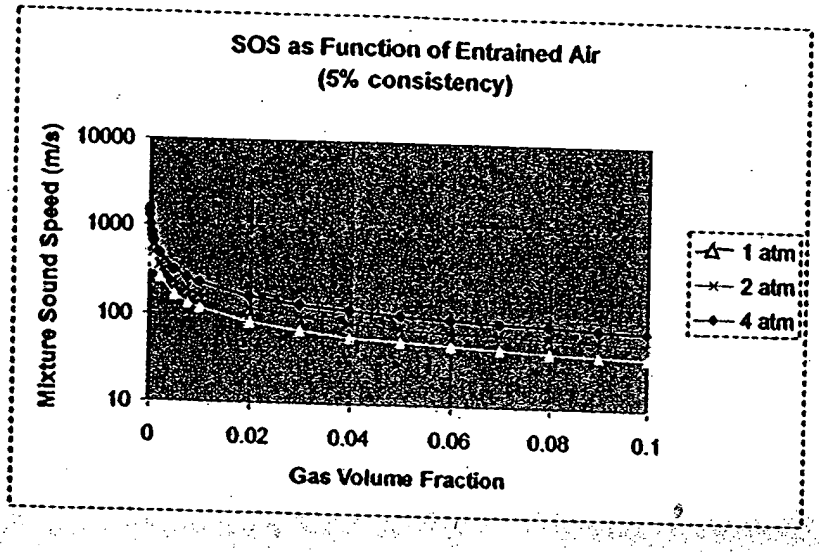

SOS as Function of Entrained Air
(5% consistency)
Mixture Sound Speed (m/s)
10000
1000
100
10
0
0.02
0.04
0.06
0.08
0.1
Gas Volume Fraction
1 atm
2 atm
4 atm

Fig. 5

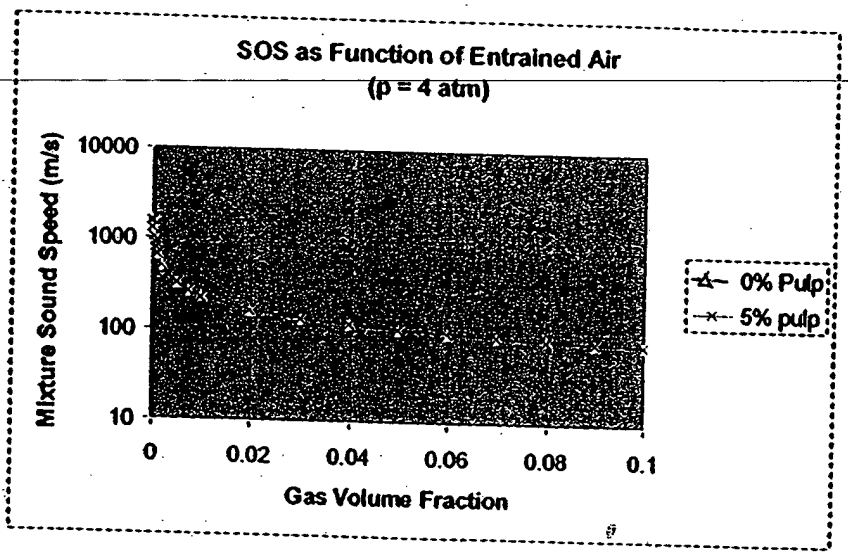

SOS as Function of Entrained Air
(p = 4 atm)
Mixture Sound Speed (m/s)
10000
1000
100
10
0
0.02
0.04
0.06
0.08
0.1
Gas Volume Fraction
0% Pulp
5% pulp

Fig. 6

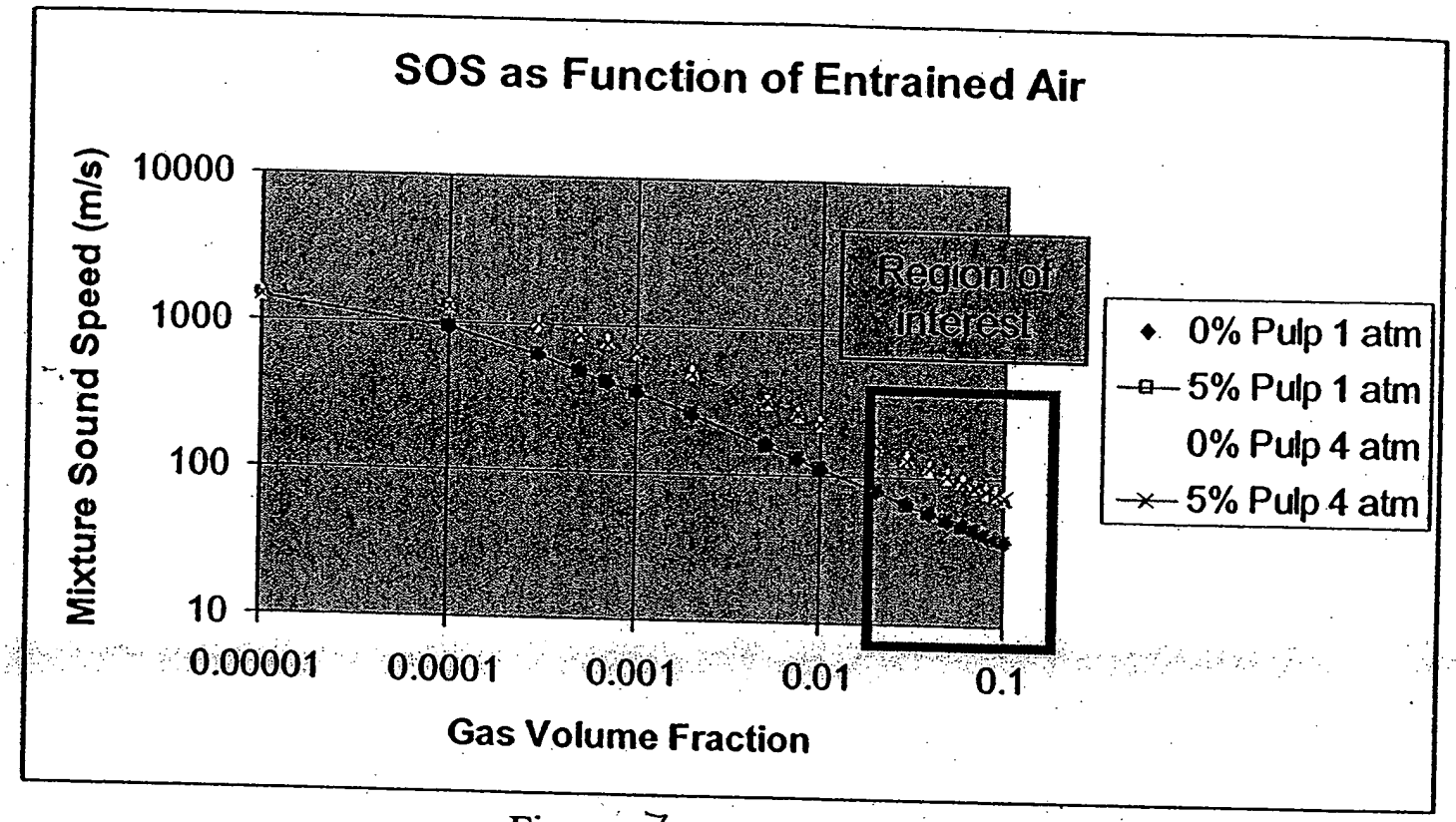

SOS as Function of Entrained Air
Mixture Sound Speed (m/s)
10000
1000
100
10
0.00001
0.0001
0.001
0.01
0.1
Gas Volume Fraction
Region of Interest
0% Pulp 1 atm
5% Pulp 1 atm
0% Pulp 4 atm
5% Pulp 4 atm

Fig. 7

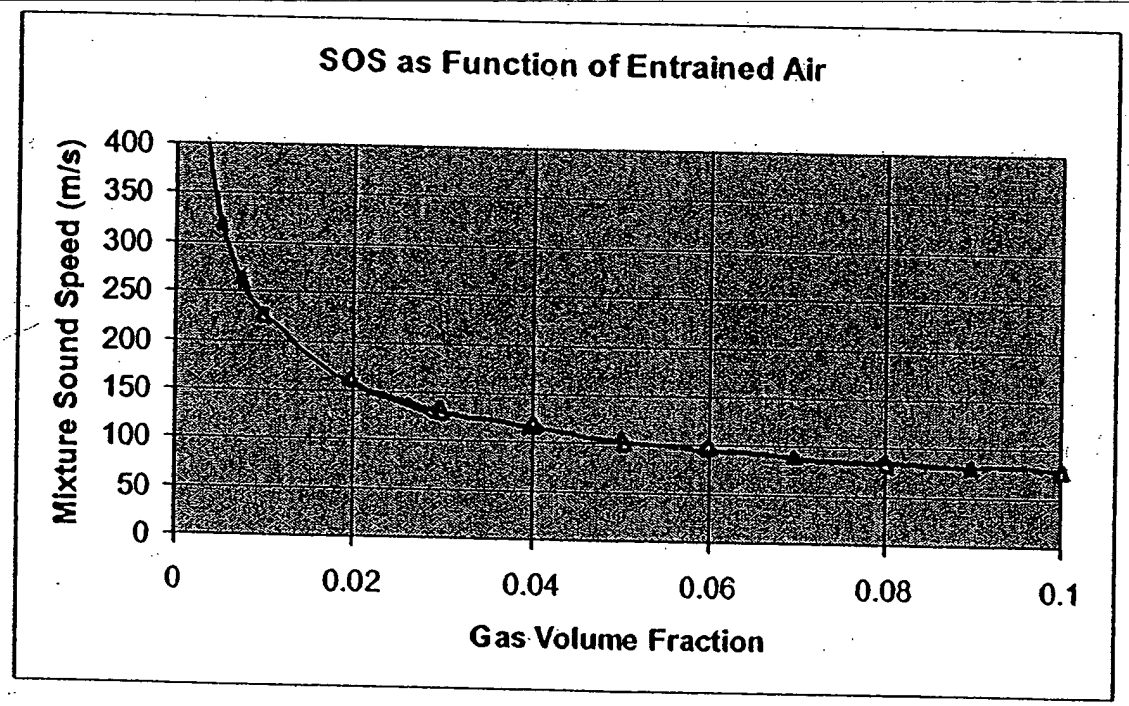

SOS as Function of Entrained Air
Mixture Sound Speed (m/s)
400
350
300
250
200
150
100
50
0
0
0.02
0.04
0.06
0.08
0.1
Gas Volume Fraction

Fig. 8

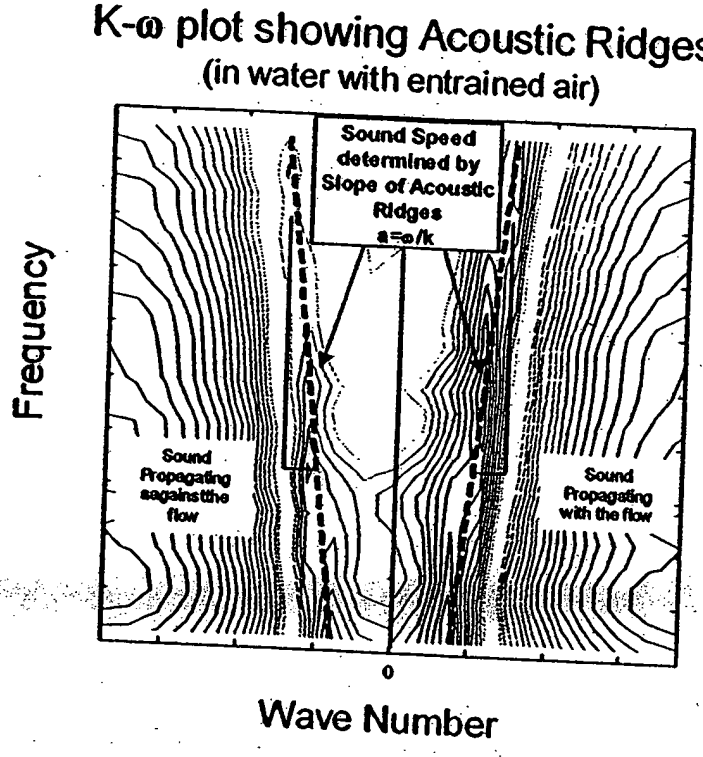

K-ω plot showing Acoustic Ridges
(in water with entrained air)
Sound Speed determined by Slope of Acoustic Ridges a=ω/k
Frequency
Sound Propagating againstthe flow
Sound Propagating with the flow
0
Wave Number

Fig. 9

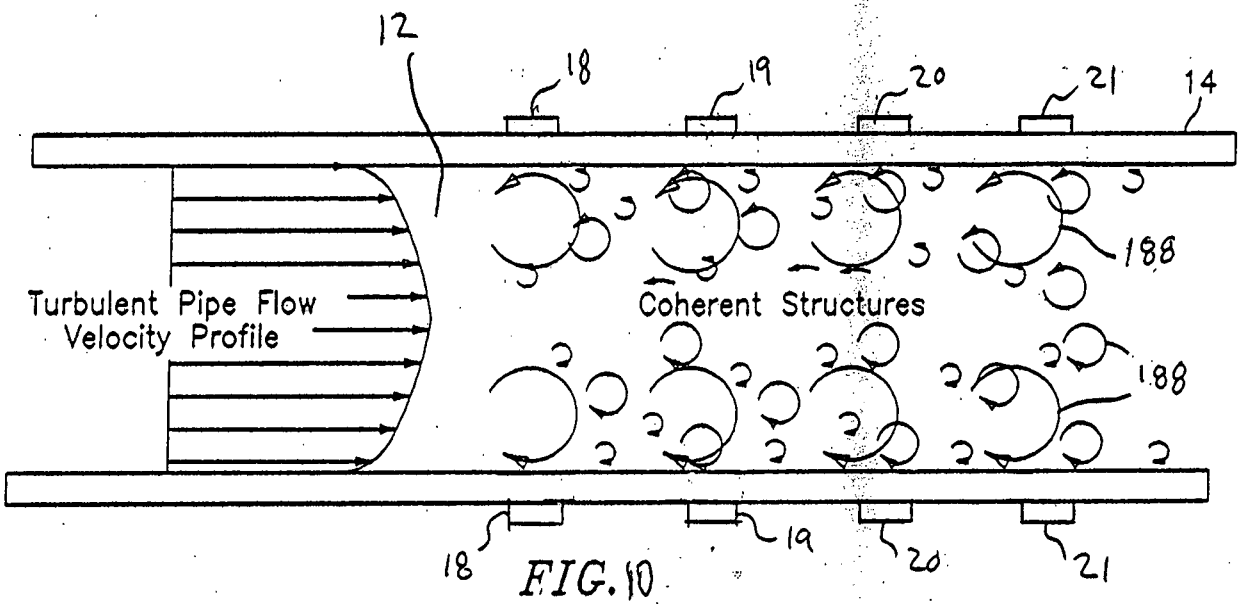

12
18
19
20
21
14
188
Turbulent Pipe Flow
Velocity Profile
Coherent Structures
188
18
19
20
21

FIG. 10

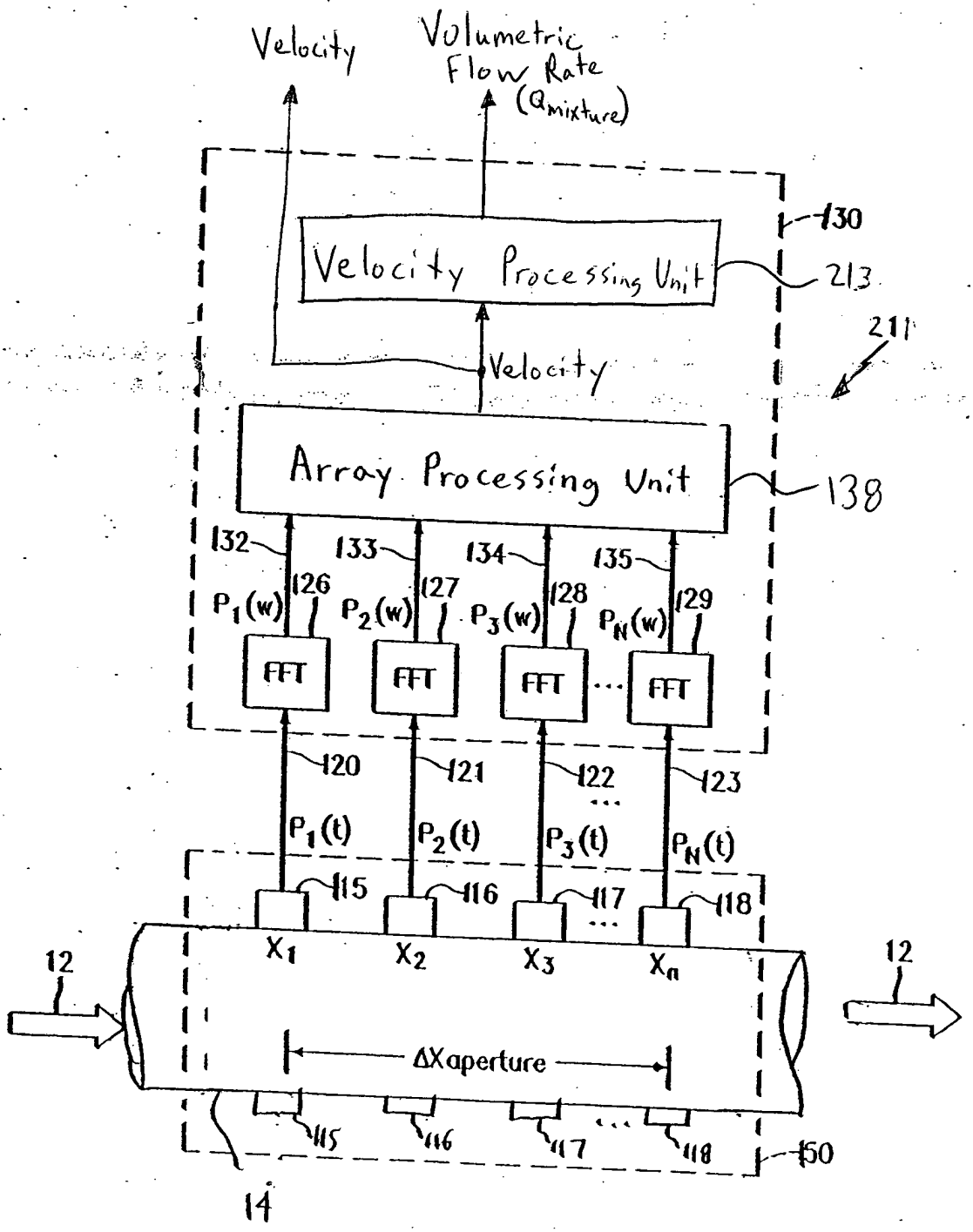

Velocity
Volumetric Flow Rate ($Q_{mixture}$)
130
Velocity Processing Unit
213
211
Velocity
Array Processing Unit
138
132
133
134
135
126
127
128
129
$P_1(w)$
$P_2(w)$
$P_3(w)$
$P_N(w)$
FFT
FFT
FFT
FFT
120
121
122
123
$P_1(t)$
$P_2(t)$
$P_3(t)$
$P_N(t)$
115
116
117
118
X_1
X_2
X_3
X_n
12
12
$\Delta X_{aperture}$
115
116
117
118
150
14

FIG. 11

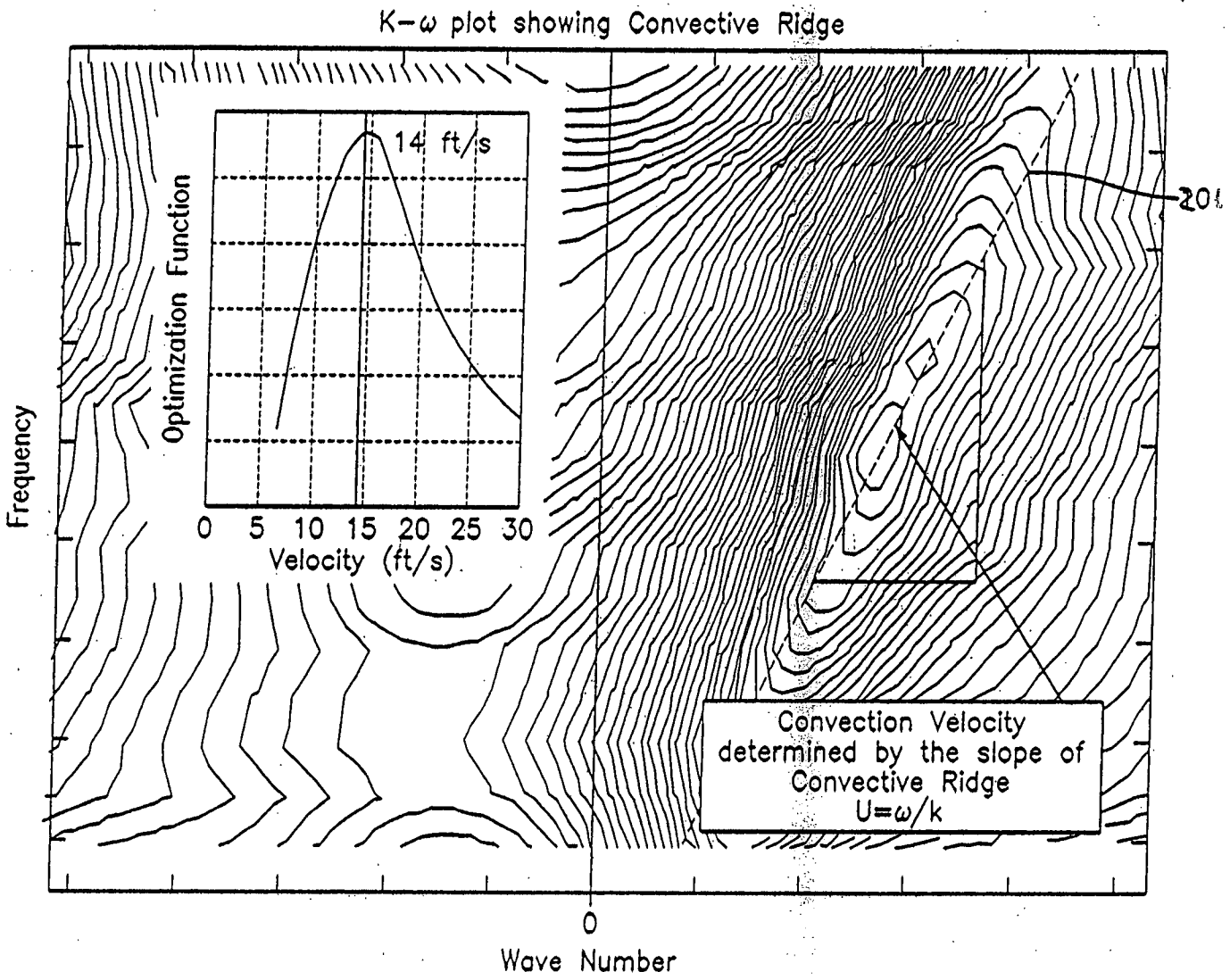

K−ω plot showing Convective Ridge
Optimization Function
14 ft/s
0 5 10 15 20 25 30
Velocity (ft/s)
Frequency
201
Convection Velocity
determined by the slope of
Convective Ridge
U=ω/k
0
Wave Number

FIG. 12

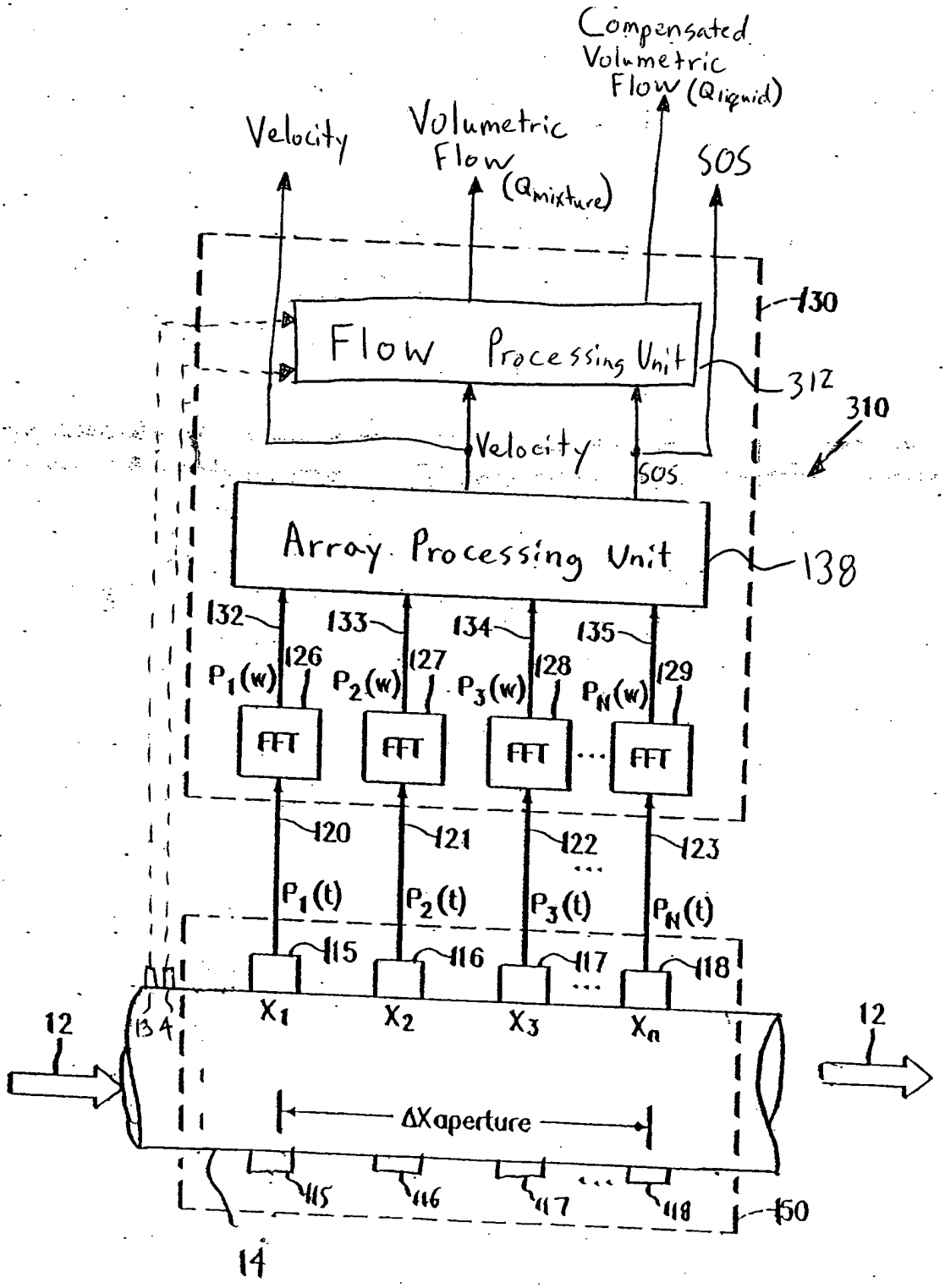

Compensated Volumetric Flow (Q_{liquid})
Velocity
Volumetric Flow ($Q_{mixture}$)
SOS
130
Flow Processing Unit
312
310
Velocity
SOS
Array Processing Unit
138
132
133
134
135
$P_1(w)$
126
$P_2(w)$
127
$P_3(w)$
128
$P_N(w)$
129
FFT
FFT
FFT
FFT
120
121
122
123
$P_1(t)$
$P_2(t)$
$P_3(t)$
$P_N(t)$
115
116
117
118
12
13
14
X_1
X_2
X_3
X_n
12
$\Delta X_{aperture}$
115
116
117
118
150

FIG. 13

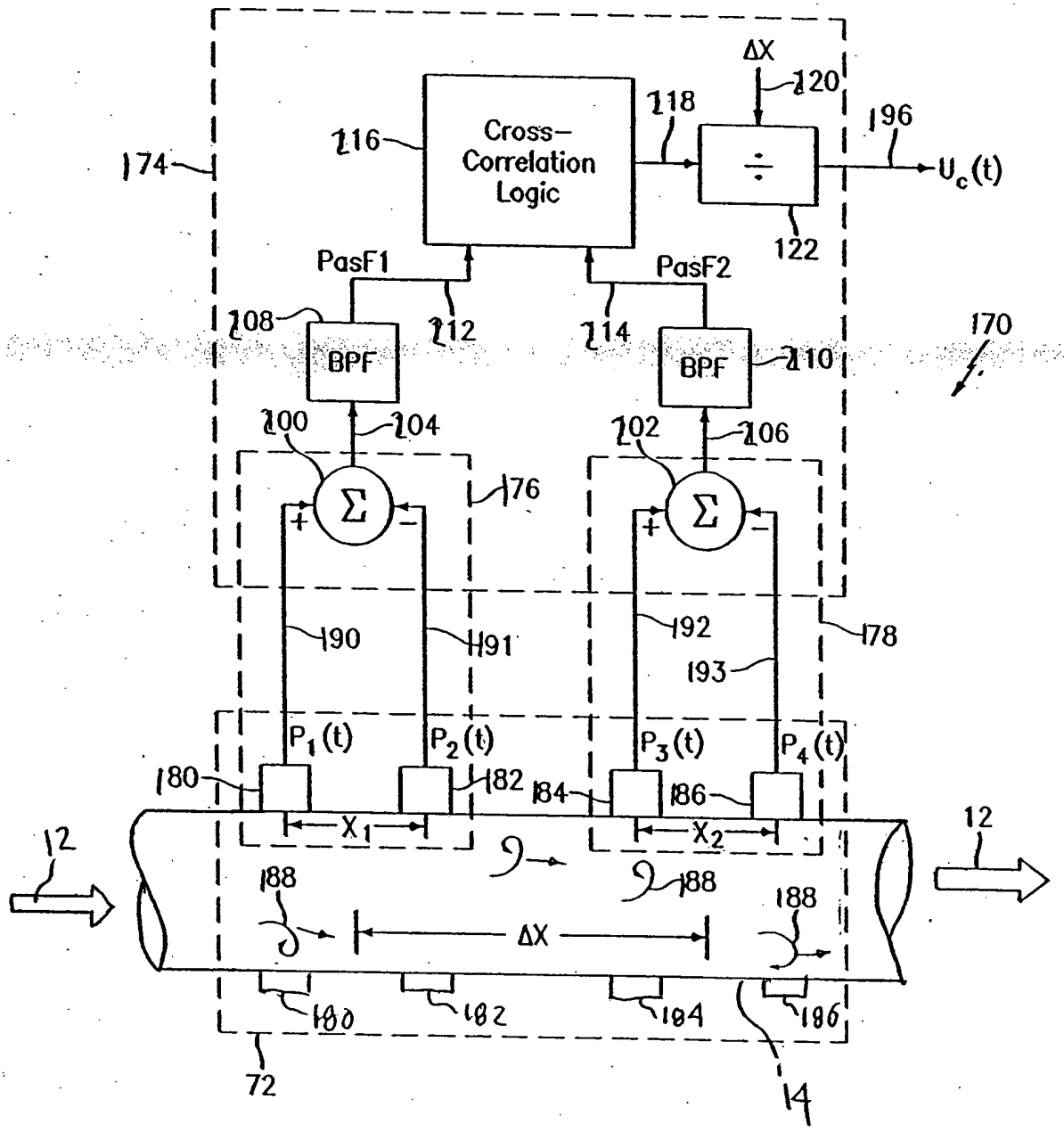

174
116
Cross–
Correlation
Logic
118
ΔX
120
196
÷
$U_c(t)$
122
PasF1
PasF2
108
112
114
BPF
BPF
110
170
100
104
102
106
Σ
Σ
176
178
190
191
192
193
$P_1(t)$
$P_2(t)$
$P_3(t)$
$P_4(t)$
180
182
184
186
X_1
X_2
12
12
188
188
188
ΔX
180
182
184
186
72
14

FIG. 14

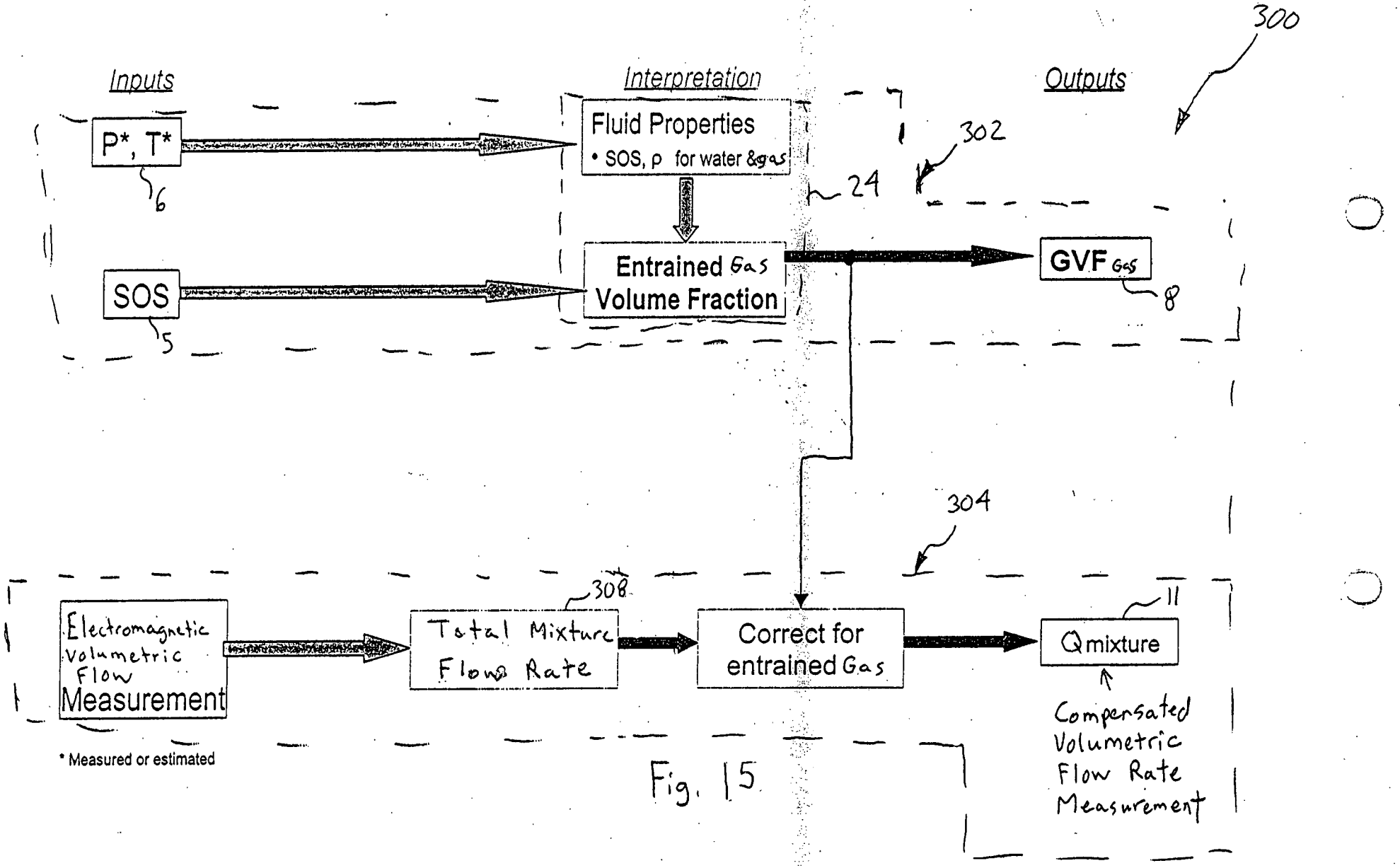

300
Inputs
Interpretation
Outputs
P*, T*
6
Fluid Properties
• SOS, ρ for water & gas
302
24
SOS
5
Entrained Gas Volume Fraction
GVF Gas
8
304
Electromagnetic Volumetric Flow Measurement
308
Total Mixture Flow Rate
Correct for entrained Gas
11
Qmixture
Compensated Volumetric Flow Rate Measurement
* Measured or estimated

Fig. 15

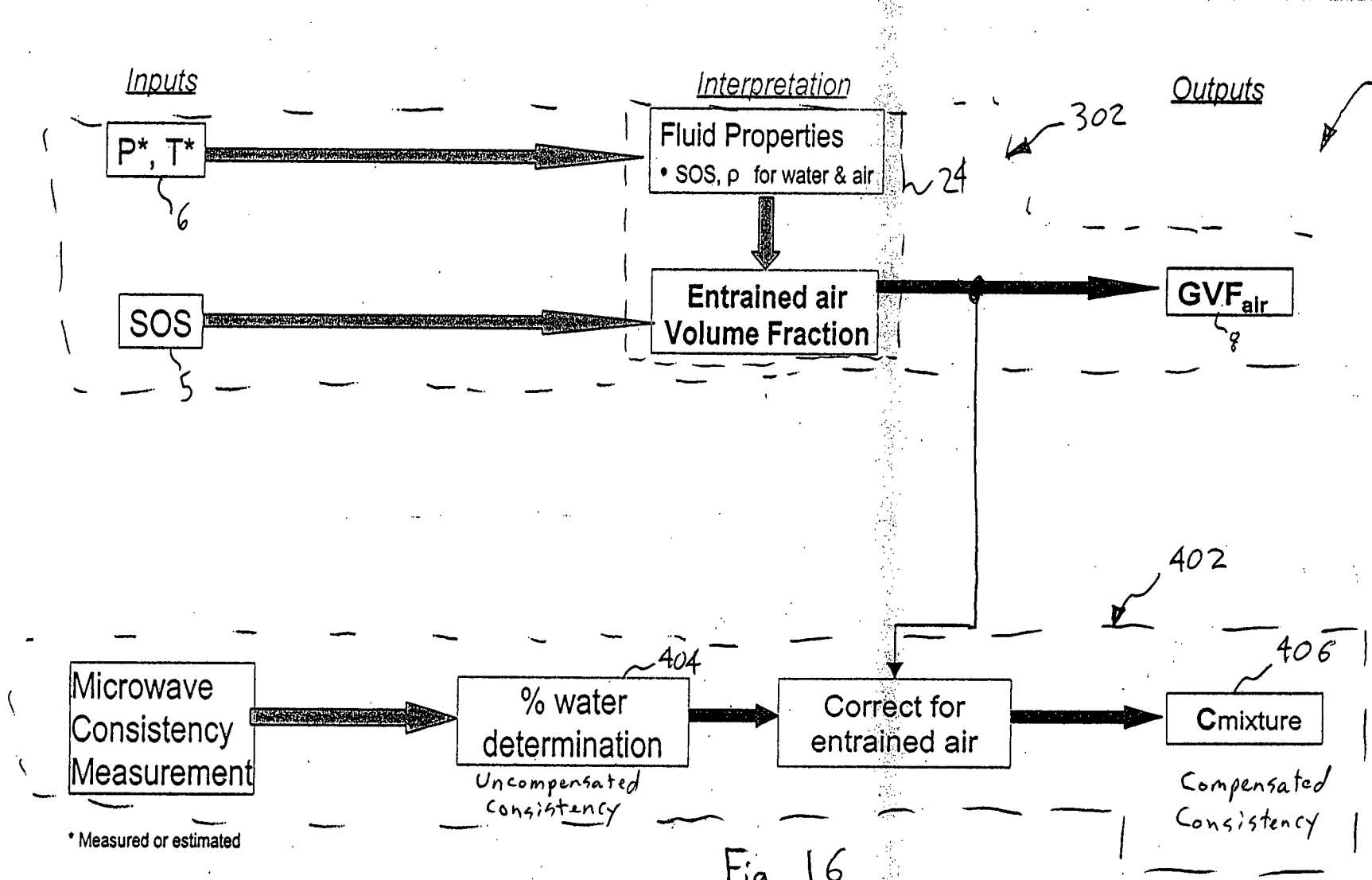

400
Inputs
Interpretation
Outputs
P*, T*
6
Fluid Properties
• SOS, ρ for water & air
24
302
SOS
5
Entrained air Volume Fraction
GVF air
8
402
Microwave Consistency Measurement
* Measured or estimated
404
% water determination
Uncompensated Consistency
Correct for entrained air
406
Cmixture
Compensated Consistency

Fig. 16

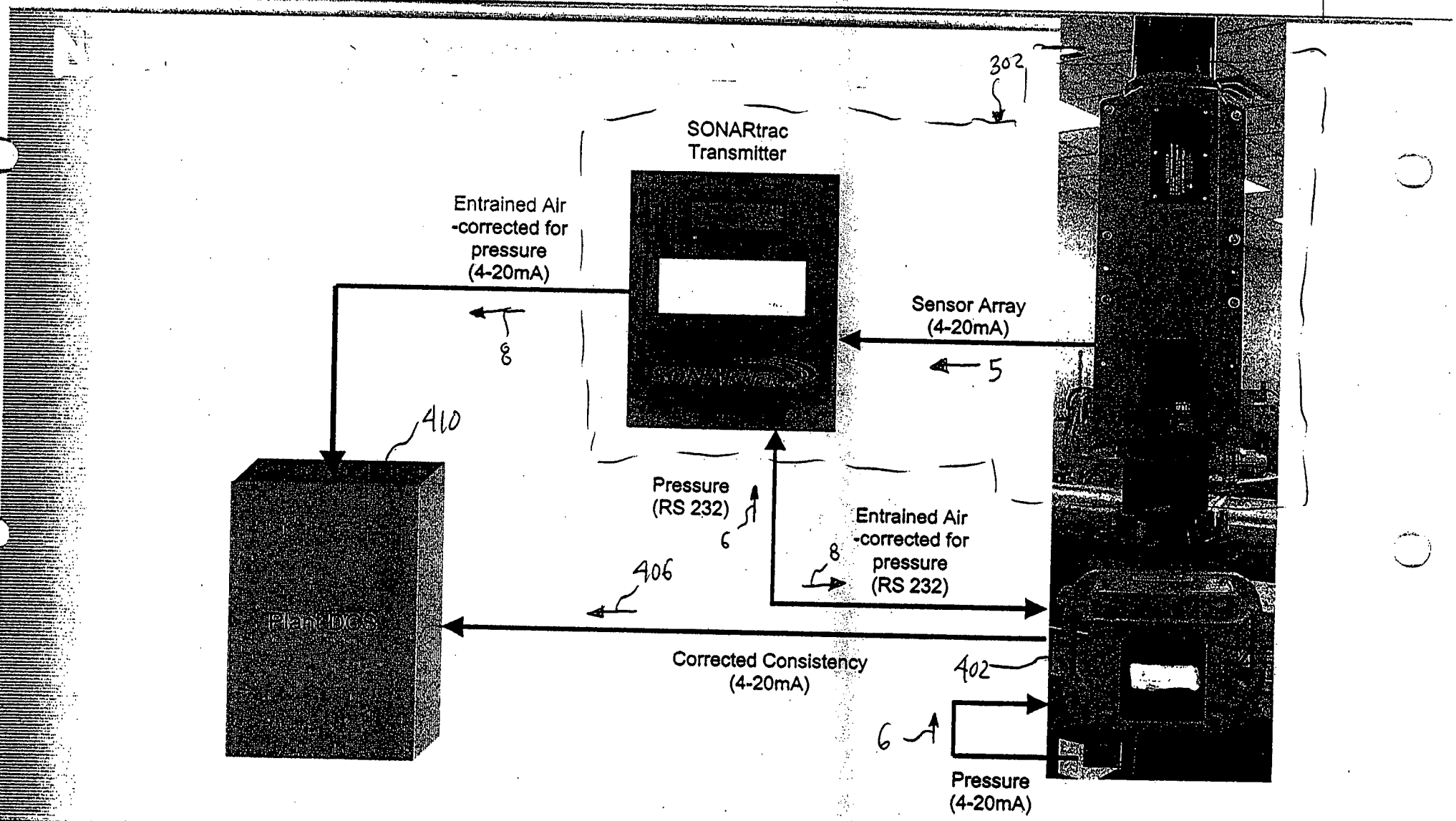
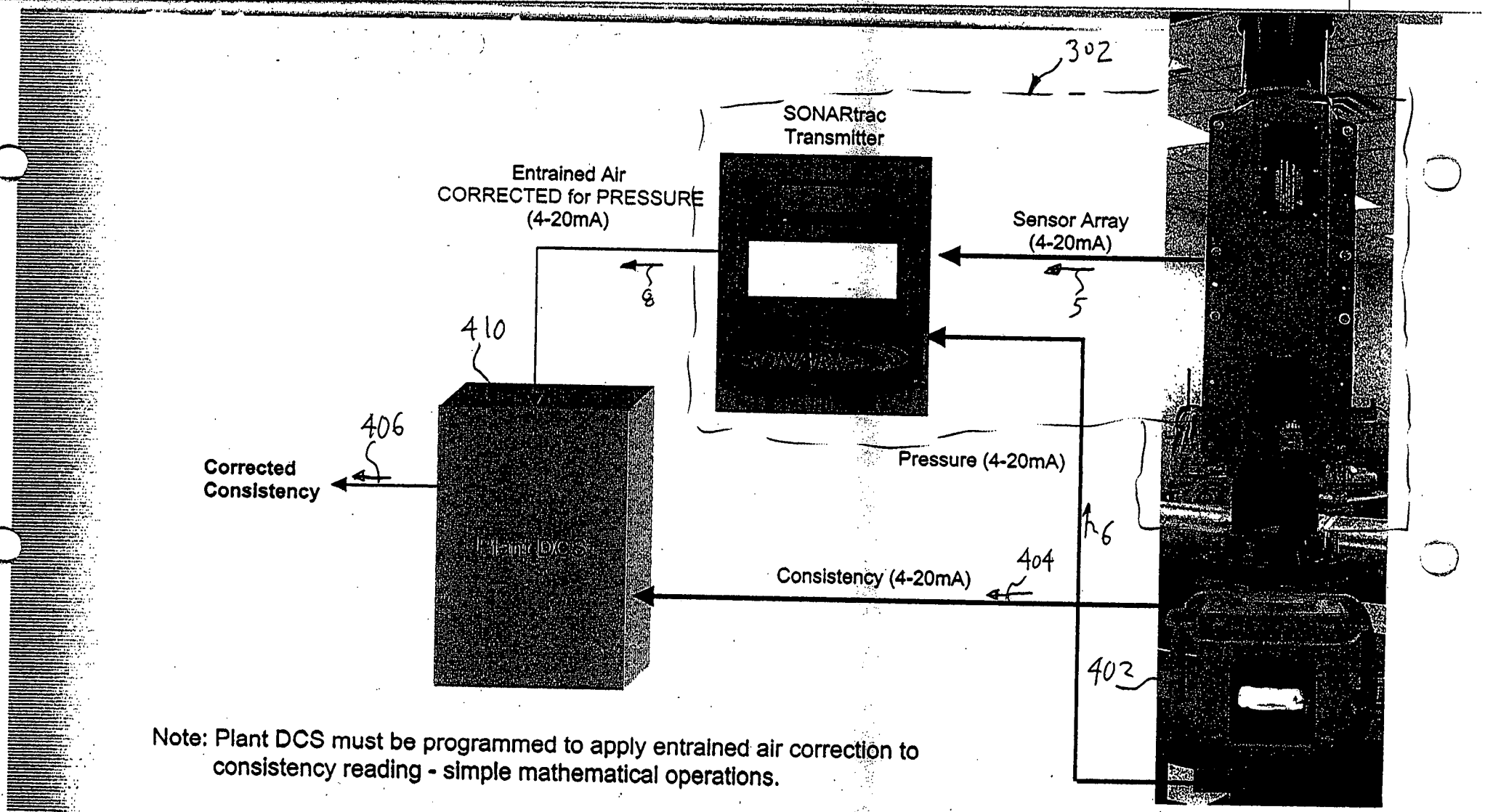
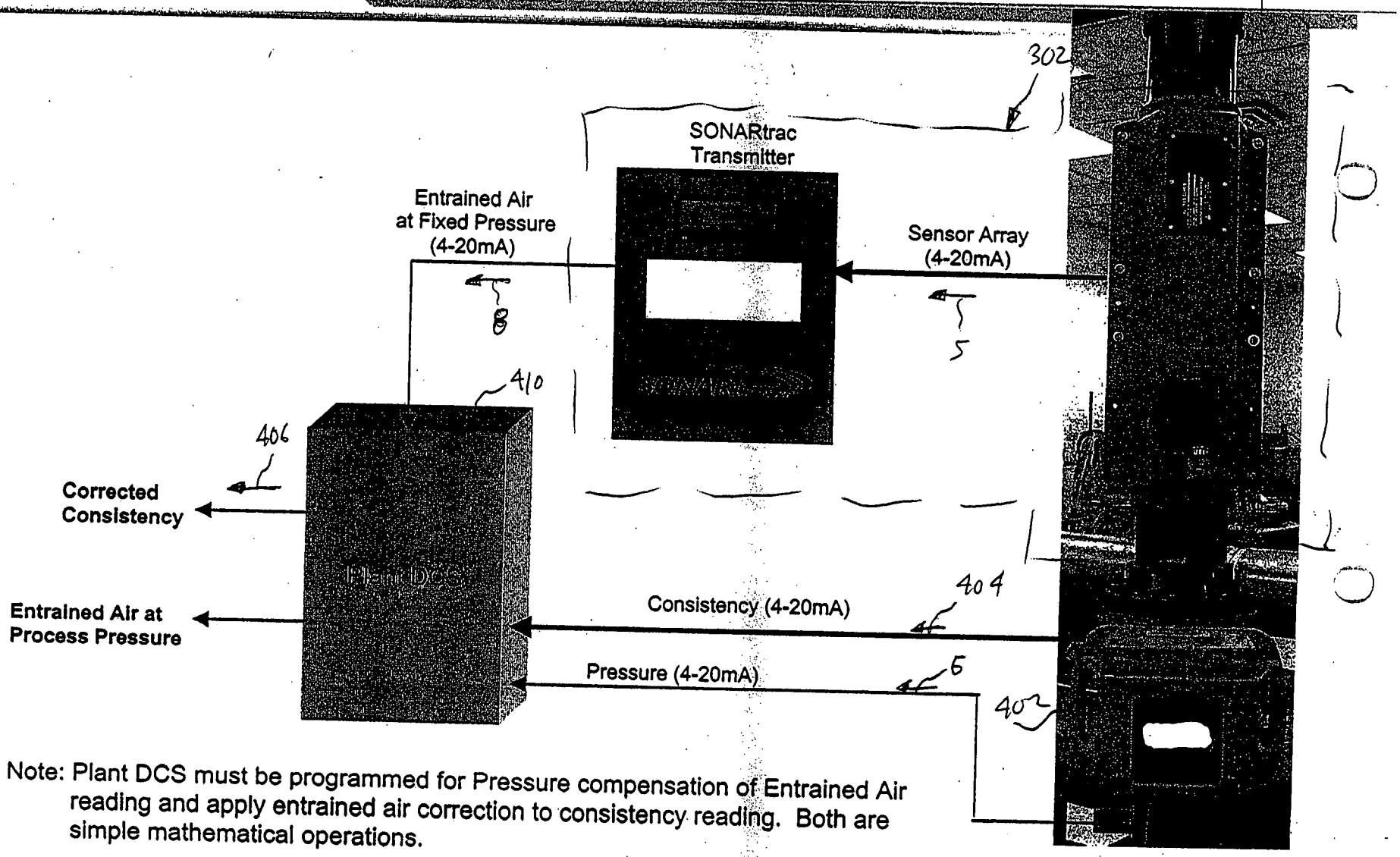

302
SONARtrac
Transmitter
Entrained Air
-corrected for
pressure
(4-20mA)
8
Sensor Array
(4-20mA)
5
410
Pressure
(RS 232)
6
Entrained Air
-corrected for
pressure
(RS 232)
8
406
Plant DCS
Corrected Consistency
(4-20mA)
402
6
Pressure
(4-20mA)

Fig. 17



Note: Plant DCS must be programmed to apply entrained air correction to consistency reading - simple mathematical operations.

Fig. 18



Note: Plant DCS must be programmed for Pressure compensation of Entrained Air reading and apply entrained air correction to consistency reading. Both are simple mathematical operations.

Fig. 19

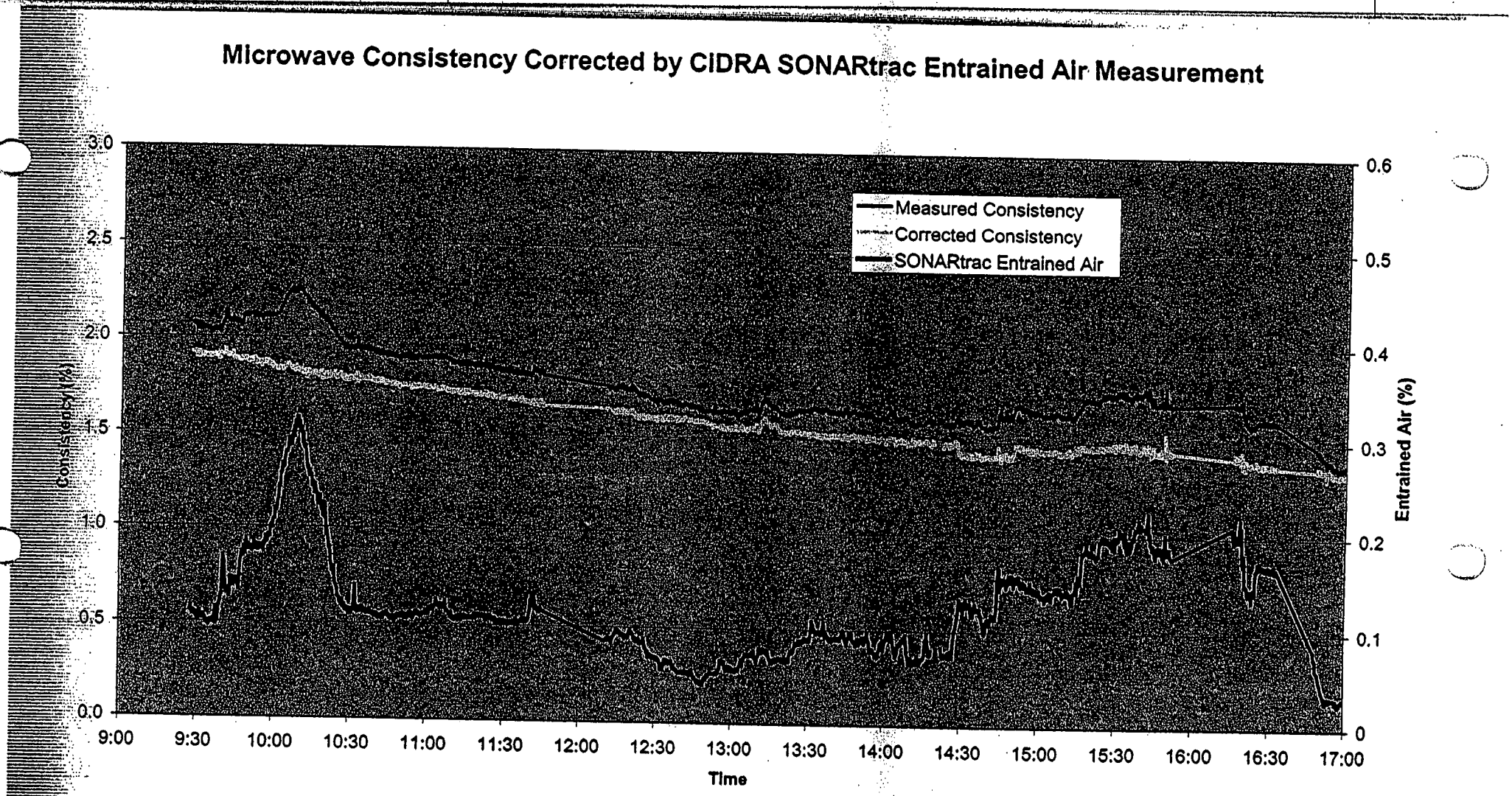

Microwave Consistency Corrected by CiDRA SONARtrac Entrained Air Measurement
Measured Consistency
Corrected Consistency
SONARtrac Entrained Air
Consistency (%)
Entrained Air (%)
Time
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.6
0.5
0.4
0.3
0.2
0.1
0
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00

Fig. 20

Macro Bubble Testing Shows Ability to Correct Microwave Consistency Analyzer

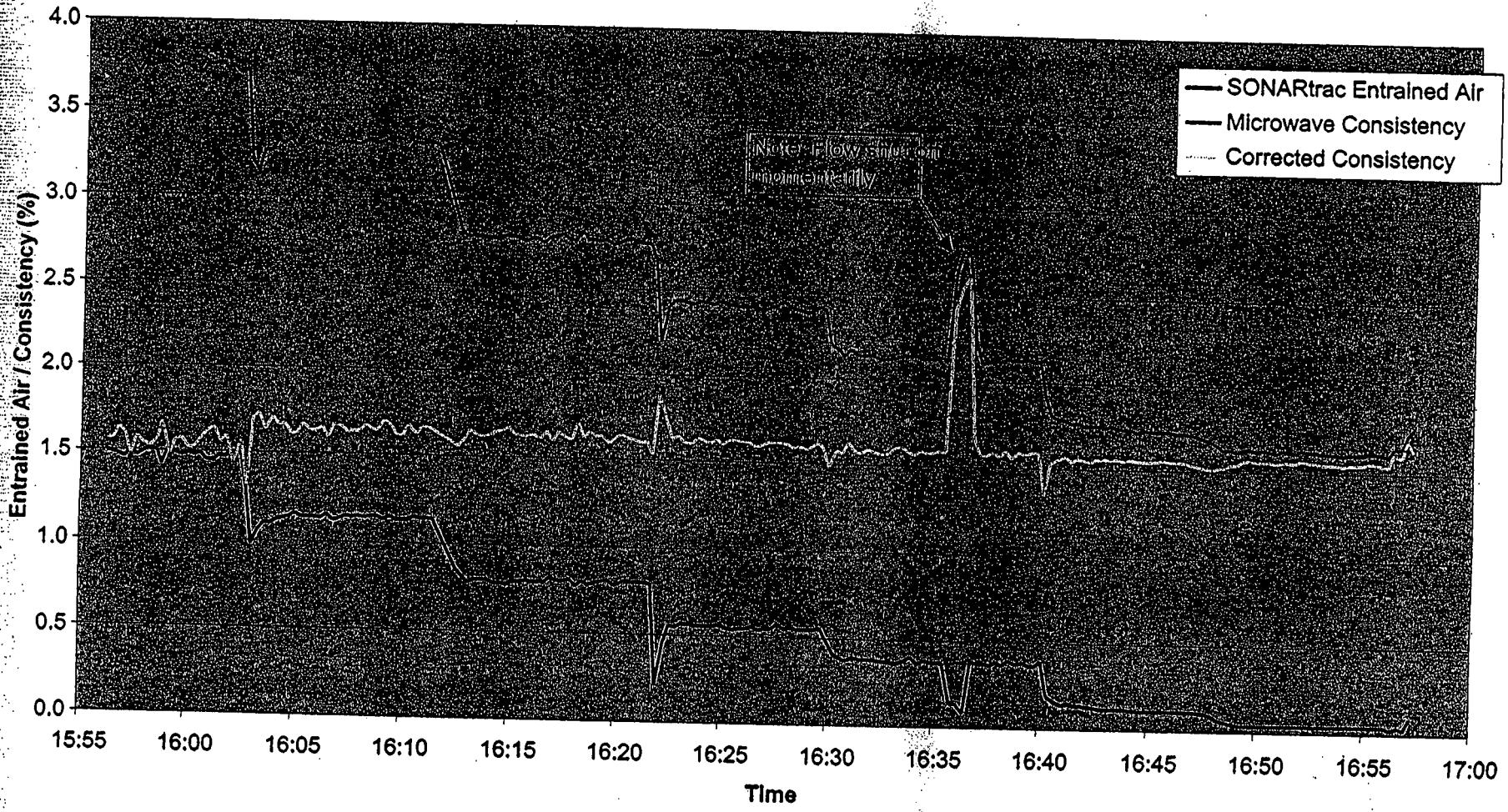


Fig. 21

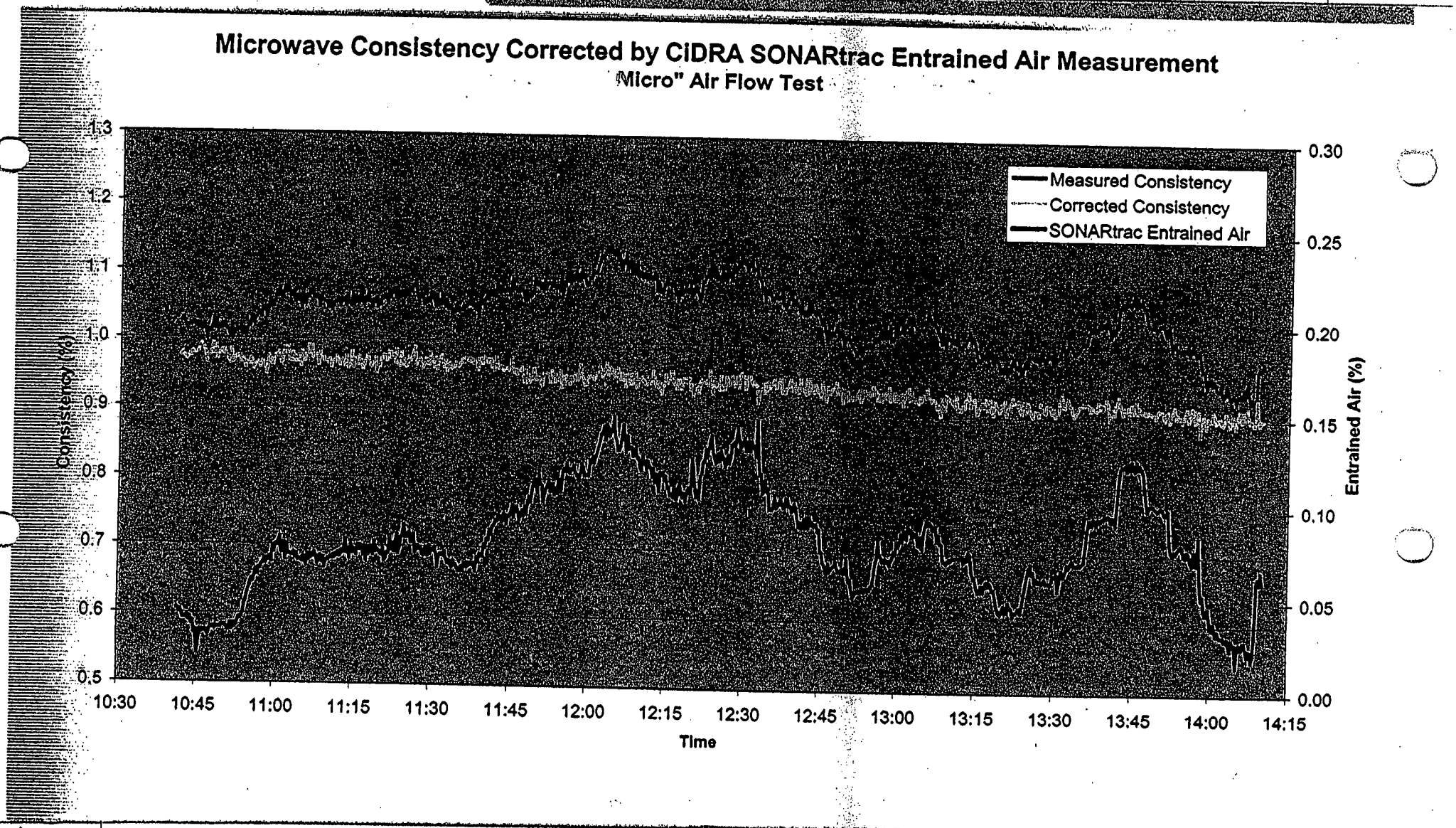

Microwave Consistency Corrected by CiDRA SONARtrac Entrained Air Measurement
Micro" Air Flow Test
Measured Consistency
Corrected Consistency
SONARtrac Entrained Air
Consistency (%)
Entrained Air (%)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.30
0.25
0.20
0.15
0.10
0.05
0.00
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
Time

Fig. 22

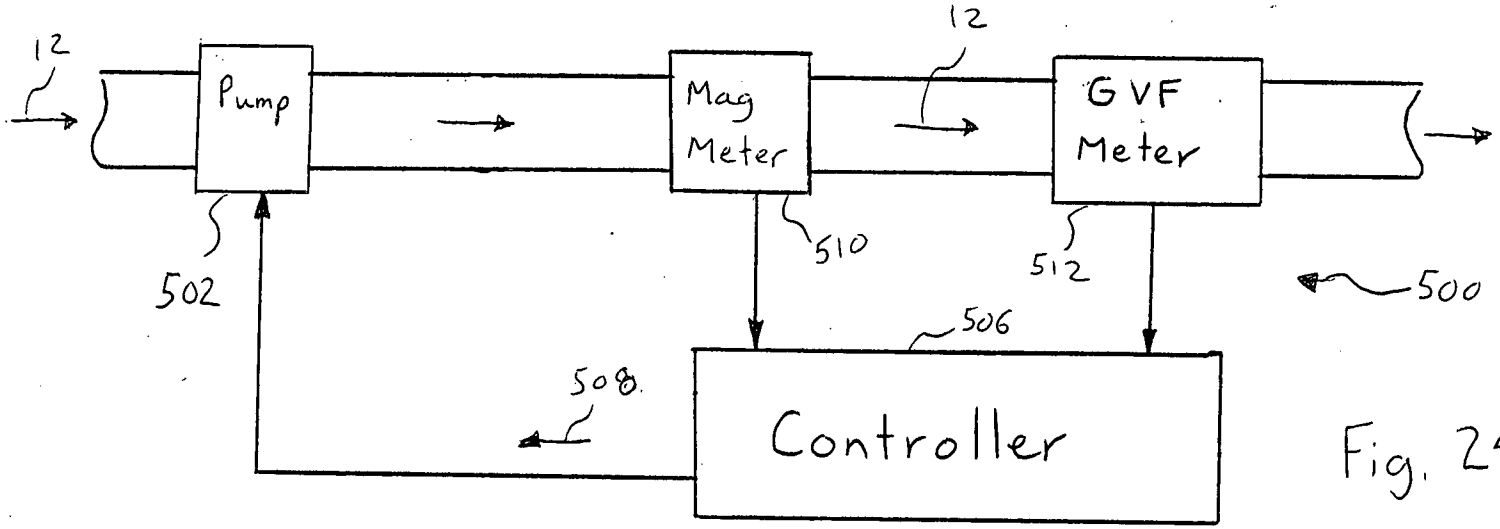

12
Pump
Mag Meter
12
GVF Meter
502
510
512
500
506
508
Controller

Fig. 24

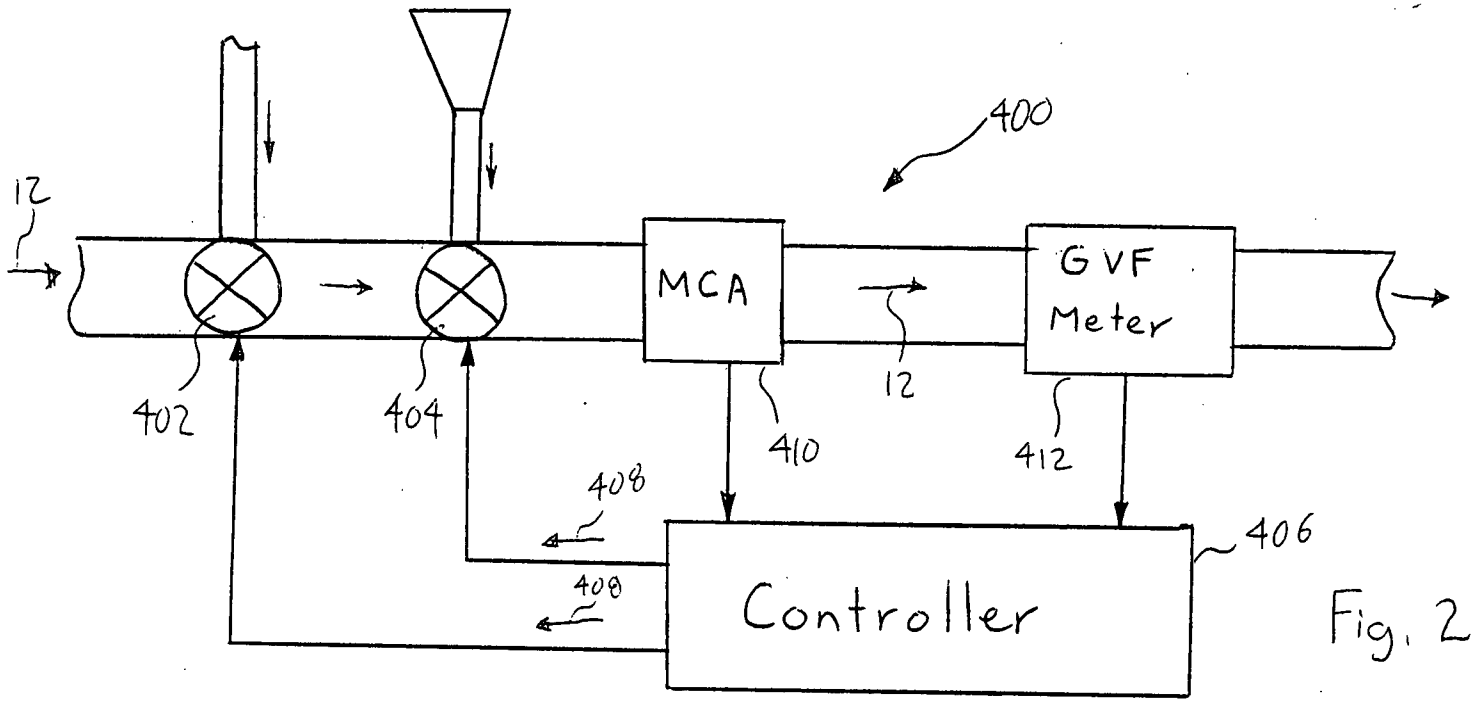

400
12
MCA
GVF Meter
402
404
12
410
412
408
406
408
Controller

Fig. 23